Appendix B

Alternative Emission Estimation Methods

ALTERNATIVE EMISSION ESTIMATION METHODS

This appendix identifies emission estimation methods developed by various groups for several fugitive dust source categories not addressed in the main body of the handbook. It also includes emission estimation methods for categories addressed in the main body of the handbook that are either still in the developmental stage and have not been approved by federal or state agencies, or were developed many years ago and have fallen out of favor. Because many of these methods have not been peer-reviewed, the reader is cautioned in the use of the emission factors included in these emission estimation methods. The emission estimation methods discussed here include:

- an early USEPA method for agricultural tilling,
- an early USEPA method and a California Air Resources Board (CARB) method for agricultural harvesting,
- a CARB method for cattle feedlots,
- emission estimation methods developed by AeroVironment for miscellaneous minor fugitive dust sources (leaf blowers, equestrian centers, landfills, and truck wake turbulence of unpaved shoulders),
- an early USEPA method for active storage pile wind erosion,
- an early USEPA method for uncovered haul trucks,
- a Desert Research Institute (DRI) method for unpaved shoulders, and
- four methods for open area wind erosion: the Draxler method, the UNLV method, the Great Basin Unified APCD method, and the DEJF method.

Appendix B also includes a discussion of a method developed by DRI to measure the silt loading for paved roads.

Agricultural Tilling

In 1983, Midwest Research Institute developed a PM10 emission factor for fugitive dust generated by agricultural tilling for the USEPA.[1] The emission factor equation developed by MRI for soils with a mean silt content (s) of 18% was given as:

$$EF = 1.01\ s^{0.6}$$

where,

EF = PM10 emission factor (lb/acre-pass)

s = silt content of surface soil (%)

This emission factor for agricultural tilling was adopted by the USEPA in their 4th edition of AP-42. However, the chapter on agricultural tilling was dropped from subsequent editions of AP-42.

Agricultural Harvesting Operations

<u>USEPA Method</u>. AP-42 includes emission factors for particles less than 7µm in aerodynamic diameter for cotton, wheat and sorghum harvesting operations.[2] These

sections of AP-42 have not been updated since 1995. The PM7 emission factors (lb/square mile) for harvesting cotton, wheat and sorghum are presented in Table 1.

Table B-1. USEPA's PM7 Emission Factors for Harvesting (lb/square mile)

Operation (units)	Harvesting	Loading	Transport	Total
Harvesting cotton with a 2-row picker with a basket	2.6	0.40	2.5	5.5
Harvesting cotton with a stripper[a]	24	0.32	1.6	26
Harvesting wheat	0.96	0.07	0.65	1.7
Harvesting sorghum	6.5	0.13	1.2	7.8

[a] Assumes 2% of all strippers are 4-row models with baskets and of the remainder 40% are 2-row models pulling trailers and 60% are 2-row models with mounted baskets.

The emission factors for harvesting cotton are based on an average machine speed of 3 mph for pickers and 5 mph for strippers, a basket capacity of 240 lb, a trailer capacity of 6 baskets, a lint cotton yield of 1.17 bales/acre for pickers and 0.77 bales/acre for strippers, and a transport speed of 10 mph. The emission factors for harvesting wheat and sorghum are based on an average combine speed of 7.5 mph, a combine swath width of 20 feet, a field transport speed of 10 mph, a truck loading time of 6 minutes, a truck capacity of 13 acres for wheat and 7 acres for sorghum, and a filled truck travel time of 2 minutes per load.

CARB Method. The California Air Resources Board (CARB) has published PM10 emission estimation methods for fugitive dust emissions originating from agricultural harvesting operations.[3] At this time, emission factors have been measured in California for harvesting cotton, almonds and wheat. All other crops are assigned emission factors by scaling the emission factors measured for these three crops. The measured PM10 emission factors for harvesting cotton, wheat and almonds are 3.4, 5.8, and 40.8 lb/acre, respectively. PM10 emission factors for several of the major crops grown in California were assigned as follows:

- sugar beets, onions and potatoes: 50% of that for cotton
- vine crops and tomatoes: 5% of that for cotton
- fruit trees: 2.5% of that for cotton
- corn: 50% of that for wheat
- walnuts: same as almonds.

The complete list of harvesting emission factors assigned to over 200 crops can be obtained from CARB's website (www.arb.ca.gov/emisinv/areasrc/full pdf; see Section 7.5 "Agricultural Harvest Operations").

Cattle Feedlots

CARB has published PM10 emission factors for cattle feedlots and dairies.[3] These emission factors are 28.9 lb per 1,000 head of feedlot cattle per day, and 6.7 lb per 1,000 head of dairy cattle per day. The dairy PM10 emission factor is applied only to producing dairy cows since the emissions from support animals (bulls, heifers, calves) are included in the emission factor.

Miscellaneous Sources (Leaf Blowers, Equestrian Centers, Landfills, and Turbulent Wake from Large Vehicles)

AeroVironment (AV), under contract to the South Coast AQMD, conducted an assessment of PM10 emission factors for sources of fugitive dust not included in the District's inventory.[4] Rather than conducting field measurements, AV based their analysis on telephone interviews, engineering calculations, visual observations and literature searches. Study categories included leaf blowers, equestrian centers, landfills, and wake turbulence from large vehicles moving adjacent to unpaved road shoulders or disturbed vacant lands. AV developed an emission factor for equestrian centers using vehicular travel on unpaved roads as a surrogate. The AP-42 methodology used to calculate fugitive dust emissions from construction operations, which are primarily due to heavy vehicles traveling on unpaved roads, was adapted for landfills. AV's methodology contains several inappropriate assumptions as well as mathematical errors.[5]. Thus, the emission factors derived by AV are suspect and are not reproduced here. It should be pointed out that AV concluded that even with their very conservative assumptions the total PM10 fugitive dust emissions from the sum of these four uninventoried source categories was insignificant (less than 1.5% of the PM10 inventory for the South Coast Air Basin).

Paved Roads: Silt Loading

AP-42 measurements of silt loading for paved roads involve periodic sampling from representative roads which are then used to calculate emissions. These silt loadings have been shown to be highly variable in time and space, and the labor required for their acquisition mitigates against frequent sampling that covers a wide spatial extent. DRI has developed a method named the TRAKER method[6] that relates real-time measurements to silt loading using one continuous forward-scattering nephelometer located in the wheel well of a vehicle and a second unit located on the hood of the vehicle to measure ambient background. Since suspendable dust remains close to the ground, the difference in readings between the two nephelometers is proportional to the amount of suspendable dust on the roadway surface. The TRAKER was calibrated in Las Vegas against AP-42 silt loadings determined for samples taken in the study area for a variety of visible surface loadings and traffic types and volumes. The study results showed a reasonable relationship between the continuous TRAKER measurements and actual silt loadings.

Storage Pile Wind Erosion

A total suspended particulate (TSP) emission factor for wind erosion of active storage piles was included in a USEPA report published in 1989.[7] This emission factor is not included in AP-42. Annual TSP emissions for wind blown dust from active storage piles were estimated from the following equation:

$$TSP\ (lb/year/acre\ of\ surface) = 1.7\ (s/1.5)\ (365\ [365-p]/235)\ (f/15)$$

where, s = silt content of material (weight %)
p = number of days per year with at least 0.01 inch of precipitation
f = percentage of time unobstructed wind speed is greater than 12 mph at mean pile height

The short-term (24 hour) TSP emissions estimate for wind blown dust from active storage piles was given as:

$$TSP\ (lb/acre/hour) = 0.72\ U$$

where, U = wind speed (mph)

To estimate PM10 and PM2.5 emissions, the PM10/TSP and PM2.5/TSP ratios published in AP-42 for storage piles will need to be obtained.

Uncovered Haul Trucks

A total suspended particulate (TSP) emission factors for uncovered haul trucks was included in a USEPA report published in 1989.[7] This emission factor is not included in AP-42. The hourly TSP emission estimate for uncovered haul trucks was estimated from the following equation:

$$TSP\ (lb/yd^2/hour) = 0.00015\ u$$

where, u = sum of wind speed and vehicle speed (mph)

To estimate PM10 and PM2.5 emissions, the PM10/TSP and PM2.5/TSP ratios published in AP-42 for materials handling will need to be obtained.

Unpaved Shoulders

DRI developed a PM10 emission factor for the resuspension of fugitive dust from unpaved shoulders created by the wake of high-profile vehicles such as tractor-trailers (semis) traveling on paved roads at high speed (50-65 mph).[8] The emission factor for unpaved shoulder with surface loadings of 4,500 to 5,500 g/m^2, silt content of 3 to 6%, and a surface moisture content under 1% was given as:

$$EF = 0.028 \pm 0.014\ lb/VMT$$

DRI concluded that emissions from unpaved shoulders due to smaller vehicles such as cars, vans and SUVs were negligible. It should be pointed out that the PM10 emissions were estimated utilizing nephelometers which are not quantitative for coarse particles. Thus, total PM10 emissions may be underestimated.

Wind Blown Dust from Open Areas

<u>Draxler Method</u> Based on an evaluation of available algorithms for calculating wind blown fugitive dust emissions, the WRAP expert fugitive dust panel[9] recommended the use of the algorithm developed by Draxler et al.[10] that was based on the earlier work of Marticorena et al.[11] This algorithm received the highest score on the basis of extensive field verification test results and having undergone peer review. Draxler and coworkers developed their algorithm for estimating fugitive dust emissions during desert dust storms in Iraq, Kuwait, and Saudi Arabia using a Lagrangian transport and dispersion model where the vertical dust flux was proportional to the difference in the squares of the friction velocity and threshold friction velocity. A proportionality constant was used to relate the surface soil texture to the PM10 dust emissions, and is defined as the ratio of vertical flux of PM10 to total aeolian horizontal mass flux. PM10 emissions caused by wind erosion were estimated in a stepwise process as follows:

- Step I. Obtain large scale and small scale wind fields
- Step II. Estimate sand movement (horizontal flux of saltation particles $\geq$50 µm)
- Step III. Calculate vertical resuspended dust emissions

The horizontal flux of sand, Q (µg/meter-second), was modeled as follows:

$$Q = A\,(\rho/g)\,u^{*}\,(u^{*2} - u^{*2}_{t})$$

where, A = a dimensionless constant

ρ = the density of air

g = the acceleration due to gravity

u^* = the friction velocity (m/s)

u^*_t = the threshold friction velocity (m/s) required for initiation of sand movement by the wind.

The value of A is not constant if there is wetting followed by crusting of the surface sediments, or if there is a depletion of loose particles on the surface for a "supply-limited" surface. The value of A ranges from a maximum of ~3.5 when the surface is covered with loose sand to ~0 when the surface has a smooth crust with few loose particles larger than 1 mm. Suspended dust is proportional to saltation or sandblasting as follows:

$$F = K\,Q$$

where, F = the vertical flux of dust (µg/m^2-second)

K = proportionality factor (m^{-1}) that relates the surface soil texture to PM10 dust emissions

Q = the horizontal flux of saltating particles (µg/m-second)

The value of K is not precisely known, but data sets of F versus Q are available so that estimates of K can be made for certain soils. For sand textured soils, K is estimated to be ~5.6×10^{-4} m^{-1} and A is ~2.8.

UNLV Method Under contract to the Clark County Department of Comprehensive Planning, James et al.[12] developed a wind blown fugitive PM10 dust inventory for Clark County, NV. This inventory utilized University of Nevada Las Vegas (UNLV) wind tunnel-derived estimates of wind blown fugitive dust emission factors for three categories of vacant land: disturbed vacant land, stabilized vacant land, and undisturbed native desert soils. The emission factors included geometric mean hourly "spike" corrected emission rates (tons/acre-hour) for disturbed vacant land, stabilized vacant land and undisturbed native desert soils as well as geometric mean spike emissions (ton/acre) for disturbed vacant land and undisturbed native desert soils as a function of wind speed and soil type. The emission inventory assumed that the particulate reservoir for disturbed vacant land had no limit. For every hour the sustained wind speeds were within a given wind speed category above the "spike" wind speed, the emissions were calculated. A single "spike" mass was added for each acre of vacant land for those days that the wind speed exceeded a threshold wind speed, assuming each day represented a single wind event and reservoir recharging would not have occurred during a 24-hour period. Wind speeds less than the "spike" speed were not included in the emission calculations. Because the native desert parcels have a limited PM10 reservoir, it was assumed that the reservoir would be depleted within one hour of sustained winds above the "spike" wind speed. Therefore, only one hour of emissions were calculated during each day that winds exceeded the threshold friction velocity ("spike" wind speed) for native desert parcels.

The wind speed threshold for generating fugitive dust emissions was estimated by James et al.[12] to be 20 mph for disturbed vacant land and 25 mph for native desert parcels. Because the parcels stabilized with dust suppressants had been subjected to some disturbance by vehicle traffic that may have caused some dust palliatives to break down, the initial wind threshold for this category was lower than the other categories, namely 15 mph. However, the use of dust palliatives greatly reduced the overall emission factors. Spikes were generally not observed from the stabilized parcels, and emission factors without spike corrections were used for stabilized parcels. As with native desert, it was assumed that the stabilized parcels have a limited PM10 reservoir that would be depleted within one hour of sustained winds above the threshold wind velocity. Therefore, only one hour of emissions was calculated during each day for stabilized parcels.

For a sustained wind speed of 25 mph, the geometric mean hourly spike corrected emission factors across all soil types for Clark County were estimated to be ~5 x 10^{-3} ton/acre-hour for disturbed vacant land, ~2 x 10^{-3} ton/acre-hour for native desert, and ~2 x 10^{-4} ton/acre-hour for stabilized land. The geometric mean spike emissions for a sustained wind speed of 25 mph were estimated to be ~2 x 10^{-3} ton/acre for disturbed vacant land and ~5 x 10^{-4} ton/acre for undisturbed native desert parcels. It should be pointed out that there was significant scatter in the observed data, with within category variability ranging over 1 to 2 orders of magnitude.

Great Basin Unified APCD Method Ono et al.[13] developed a method they called the Dust ID method to measure fugitive PM10 dust emissions due to wind erosion of the dry lake bed at Owens Lake, CA using an extensive sand flux monitoring network. Owens Lake is the largest single source of fugitive dust in the United States (estimated to be ~80,000 tons PM10/year). The network consisted of co-located electronic Sensits and passive Cox Sand Catchers (CSCs) deployed on a 1 km x 1 km grid covering 135 square kilometers of the lake bed with their sensor or inlet positioned 15 cm above the surface. Sensits measure the kinetic energy or the particle counts of sand-sized particles as they saltate across the surface. Due to differences in the electronic response of individual Sensits, these units had to be co-located with passive sand flux measurement devices to calibrate their electronic output and to determine the hourly sand flux. The battery powered Sensits were augmented with a solar charging system. A data logger recorded hourly Sensit data during inactive periods and switched to 5-minute data during active erosion periods. CSC's are passive instruments that are used to collect sand-sized particles that are blown across the surface during a dust event. These instruments were designed and built by the Great Basin Unified Air Pollution Control District as a reliable instrument that could withstand the harsh conditions at Owens Lake. CSC's have no moving parts and can collect sand for a month at Owens Lake without overloading the collector.

Hourly PM10 emissions from each square kilometer of the lake bed were estimated from the following equation:

$$F_a = K_f \times q$$

where, F_a = PM10 emissions flux ($g/cm^2/hr$)
q = hourly sand flux ($g/cm^2/hr$) measured at 15 cm above the surface
K_f , called the K-factor, = proportionality factor relating the PM10 emissions flux to the sand flux measured at 15 cm above the surface.

K_f values were determined by comparing CALPUFF model predictions, based on meteorological data from thirteen 10-meter towers and an Upper Air Wind Profiler to generate wind fields using the CALMET model, to observed hourly PM10 concentrations measured at six PM10 monitoring sites utilizing TEOM PM10 monitors. A K-factor of 5×10^{-5} was used to initially run the model and to generate PM10 concentration values that were close to the monitored concentrations. Hourly K-factor values were later adjusted in a post-processing step to determine the K-factor value that would have made the modeled concentration match the monitored concentration at each of the six PM10 monitor sites using the following equation:

$$K_f = K_i \left[(C_{obs} - C_{bac})/C_{mod}\right]$$

where, K_i = initial K-factor (5×10^{-5})
$C_{obs.}$ = observed hourly PM10 concentration ($\mu g/m^3$)
$C_{bac.}$ = background PM10 concentration (assumed to be 20 $\mu g/m^3$)
$C_{mod.}$ = model-predicted hourly PM10 concentration ($\mu g/m^3$)

The results showed that K_f changed spatially and temporally at Owens Lake and that the changes corresponded to different soil textures on the lake bed and to seasonal surface changes that affected erodibility. The results also showed that some source areas were active all year, while others were seasonal and sometimes sporadic. Wind tunnel tests at Owens Lake independently confirmed these seasonal and spatial changes in K_f. Ono et al.[13] concluded that the emission estimates using their Dust ID method were more accurate than the AP-42 method for estimating daily emissions, since the emissions estimates correspond to measured hourly wind erosion on the lake bed. For daily emissions, Ono and co-workers believe that AP-42 drastically overestimates the emissions at low wind speed conditions, and underestimates emissions at high wind speeds. This large discrepancy in the emission estimates is due to the use of a single threshold friction velocity for the entire erosion area in the AP-42 method. The AP-42 method and the Dust ID method of estimating emissions resulted in very close agreement for the annual emissions.

DEJF Method The WRAP Dust Emissions Joint Forum (DEJF) is currently sponsoring an extension (Phase 2) to a WGA sponsored project started in 2003 to (a) provide windblown dust emissions inventories, and (b) complete modeling simulations of the effects of those emissions on regional haze for calendar year 2002 and future year projections. The purpose of this additional effort is to improve the windblown dust emissions model developed by Mansell et al.[14] The results of the initial model runs and subsequent sensitivity simulations have demonstrated a need to revise and/or update various assumptions associated with the development of the emission inventory. To this end, revised estimation methodologies and algorithms will being evaluated in order to address various shortcomings and limitations of the current version of the model. Many of the assumptions employed in the Phase 1 methodology are related to a lack of detail in the underlying data used to characterize vacant land types and soil conditions. In addition, the current methodology relies on arbitrarily assigned threshold friction velocities and dust reservoir characteristics. Due to the paucity of wind tunnel data, Mansell et al.[14] developed fugitive dust emission factors for wind erosion of vacant land based on soil texture rather than applying the MacDougall method.[15] Mansell and coworkers concluded that the wind tunnel emission factors derived for Clark County by James et al.[12] are much greater than emission factors measured by other researchers using wind tunnels with a larger cross-section than the UNLV designed wind tunnel (6" wide by 6" high by 60" long). The results of Phase 1 of the WGA sponsored project are available on the WRAP website (www.wrapair.org).

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